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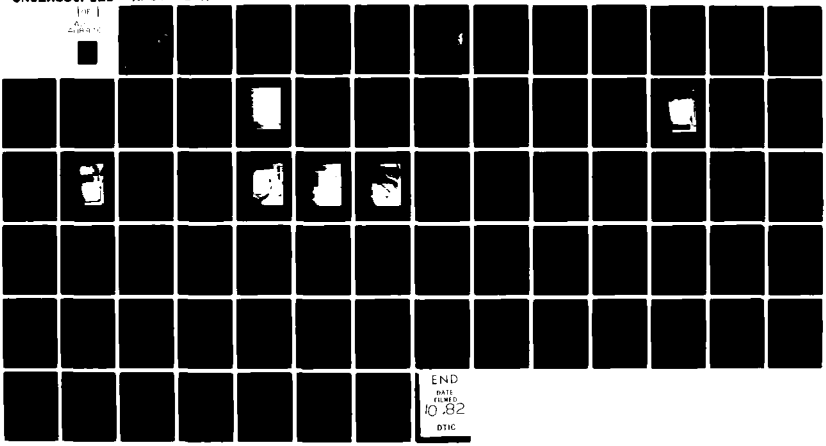

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ABSTRACT

Effects of Non-Preferred Hand on Control

A laboratory study was conducted to establish the degree to which ON-OFF control movement stereotypes apply to the non-preferred hand as well as to the preferred hand and both hands acting in unison. Controls were vertical and horizontal toggles, vertical and horizontal slide switches, push-pull switches, rotary switches, and a toggle switch mounted on a horizontal surface with forward and rearward movement. Each type of control appeared in pairs, one mounted in front of the left hand and the other in front of the right hand. Stereotyped movements were tested for type of control, plane of movement, and handedness effects. Also tested was a notion that activation of left-right pairs might be affected by subjects who assumed that symmetrical, or mirror image movements should be employed. Also tested was a notion that activation of left-right pairs of switches might be affected by subject's assumption that symmetrical, or mirror image movements should be employed.

The subjects were 120 Air Force ROTC students at Texas A&M University. Thirty of these subjects were left-handed. Twenty of the subjects performed under each of the six conditions with 5 left-handed in each group. A criterion score for stereotyped performance was set at 85 percent and Z-tests were conducted to establish significance.

Data showed strong stereotypes for turning off switches, but showed no corresponding stereotypes for turning on switches. Left-right toggles showed no stereotype for either hand. Use of the non-preferred hand showed consistently lower percentages in the expected direction but the differences were not statistically significant.

When both hands were used together, opposing movements predominated for left-right and rotary switches. Horizontally mounted toggle switches were pulled rearward for both on and off under all conditions.

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EFFECTS OF NON-PREFERRED HAND
ON CONTROL MOVEMENT STEREOTYPES

A Thesis

by

Richard Lee Lenz

Captain USAF

1982

70 pages

Masters of Science

Industrial Engineering

Texas A&M University

AFIT/CI/NR/82-32T

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EFFECTS OF NON-PREFERRED HAND

ON CONTROL MOVEMENT STEREOTYPES

A Thesis

by

Richard Lee Lenz

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R. Dale Huchingson
(Chairman of Committee)

W L Johnston
(Member)

C. M. Floyd
(Member)

W L Johnston Jr
(Head of Department)

August 1982

Data for the preferred hand showed a strong stereotype for turning off switches (down, rear, left, or counterclockwise), but showed no corresponding stereotype for turning on switches. Left-right toggles showed no stereotype with either hand. Use of the non-preferred hand consistently resulted in a smaller percentage turning the switch in the expected direction, but differences between the preferred and non-preferred hand were not statistically significant.

When both hands were used, opposing movements predominated for left-right switches and rotary switches. These reversals errors applied to mirror-image symmetry, but not to up-down symmetry. The horizontally mounted toggle was pulled rearward for both on and off functions by separate groups of subjects.

ACKNOWLEDGMENTS

I would like to thank the members of my Advisory Committee, Dr. Waymon L. Johnston, and Dr. Charles M. Stoup for their help and advice in the preparation of this paper. I would also like to extend a special thank you to my Advisory Committee Chairman, Dr. Richard D. Huchingson for his excellent advice and guidance throughout my graduate studies and in the preparation of my Thesis study. I would also extend a special thank you to Col. Henry Hill, the members and students of the 805th Detail of U. S. Air Force ROTC at Texas A&M University for their aid in the data collection phase of this study.

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INTRODUCTION

In the Handbook of Experimental Psychology (1951), P. M. Fitts defines "population stereotype" as "the relationship between a control movement and its effect which is expected by most of the population." "Most" in this definition has come to be regarded as 85% at the Texas Transportation Institute and other highway engineering research institutions (Kratz, 1981). Since the Second World War, a great many studies have been done to determine population stereotypes for many things, including switch positioning in various arrangements.

As stated by N. E. Loveless (1962), there are several factors which confound the study of population stereotypes. Loveless states that one of these factors is the hand employed for the response. Loveless goes on to state, ". . . the effect of incompatibility becomes more prominent in tasks requiring the use of the non-preferred hand or both hands, or performance at high speed." He cites Mitchell and Vince (1951), Norris and Spragg (1953), Carter and Murray (1947), and Gibbs (1950) for these observations. Loveless, later in the same paper, devotes an entire section to "The Effect of the Hand Employed for Response." He starts this section, "While this procedure (selection for preferred hand) probably gives the most generally useful results, it leaves unanswered questions about possible differences between the preferred and the non-preferred hand, and between right-handed and left-handed operators."

Citations follow the form and style of the Human Factors Journal.

Loveless goes on to state, "Differences in performance between the preferred and the non-preferred hand vary considerably from one task to another, sometimes because of anatomical features, sometimes because of differential training (Provins 1956)." He also cites Holding (1957) as finding that people are apt to turn a rotary knob clockwise for any mechanical response when using the preferred hand but do not show this tendency when using the non-preferred hand. Holding states that this may be caused when the natural tendency of the non-preferred hand and training are in conflict.

In the case of both hands moving at the same time, Loveless states that there may be a strong case for symmetrical arrangement but that it would be unwise to extend this to cases which require both hands to move laterally, or when using rotary controls. He then states, however, that no evidence is available to support this. Symmetry as used in this study will be defined as the non-preferred hand performing the mirror image operation to that of the preferred hand.

To visualize the meaning of symmetry given here, look at the apparatus panel front in Figure 1 (p. 3). Using this figure, place a mirror perpendicular to the panel front and the table top as illustrated in Figure 2 (p. 4). With this configuration, a subject performing a right-handed operation on the switches on the right side of the panel would have a "symmetrical" action imaged in the mirror. The image in the mirror would be the same as the action of the left hand in a symmetrical two handed operation. If the action of the right hand were to push the up-down toggle at the top of the panel down, the

ABSTRACT

Effects of Non-Preferred Hand on Control
Movement Stereotypes (August 1982)
Richard Lee Lenz, B.M.E., General Motors Institute
Chairman of Advisory Committee: R. Dale Huchingson

A laboratory study was conducted to establish the degree to which ON-OFF control movement stereotypes apply to the non-preferred hand as well as to the preferred hand and both hands acting in unison. Controls were vertical and horizontal toggles, vertical and horizontal slide switches, push-pull switches, rotary switches, and a toggle switch mounted on a horizontal surface with forward and rearward movement. Each type of control appeared in pairs, one mounted in front of the left hand and the other in front of the right hand. Stereotyped movements were tested for type of control, plane of movement, and handedness effects. Also tested was a notion that activation of left-right pairs might be affected by subjects who assumed that symmetrical, or mirror image movements should be employed.

The subjects were tested individually under one of six conditions: turning on or off a system with the preferred hand, the non-preferred hand, or both hands simultaneously. Order of adminstration was random and indicated by the onset of a light which remained on after switch activation. Subjects were 120 Air Force ROTC students, 30 of which were left-handed. Twenty subjects performed under each of the six conditions. A criterion score for stereotyped performance was set at 85 percent and Z-tests were concducted to establish significance.

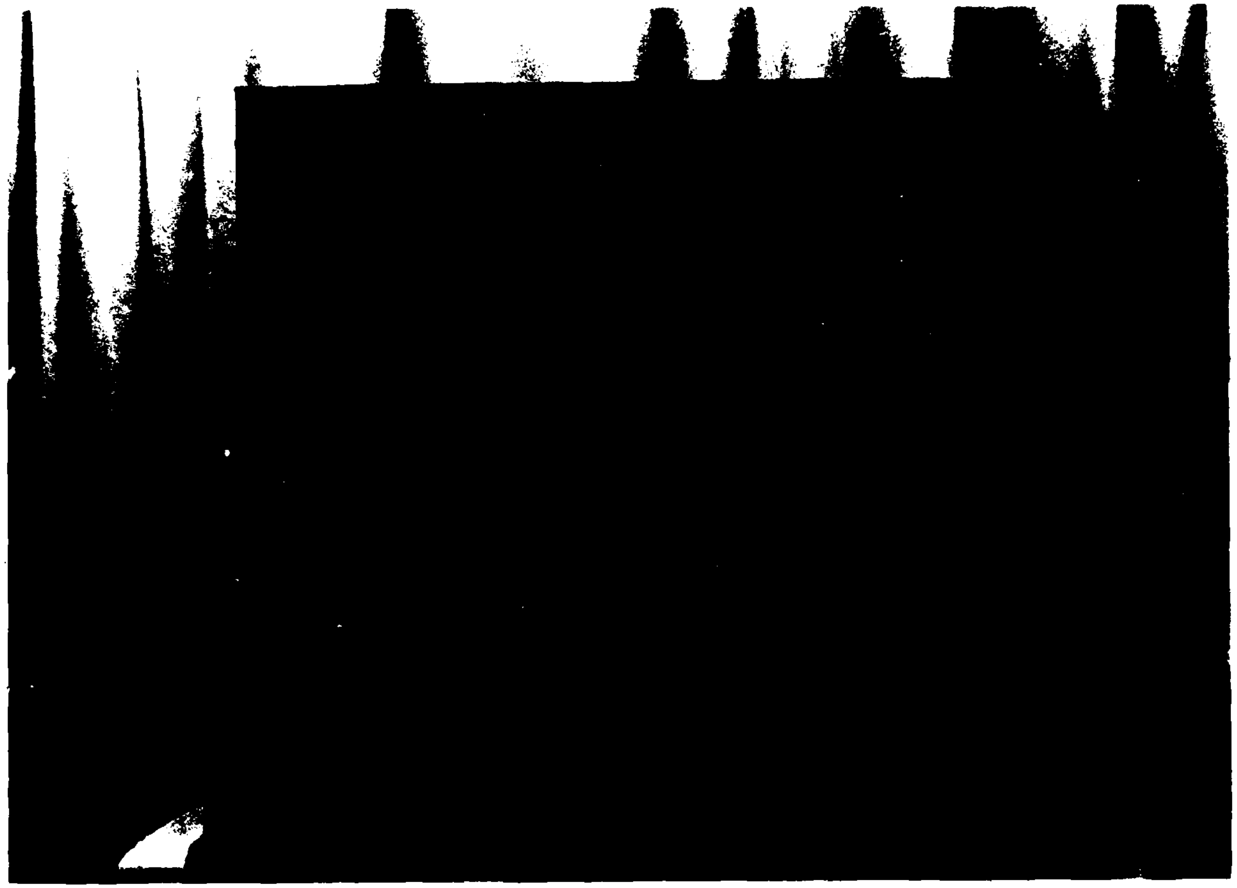

Figure 1 The experimental apparatus presented to the subjects.

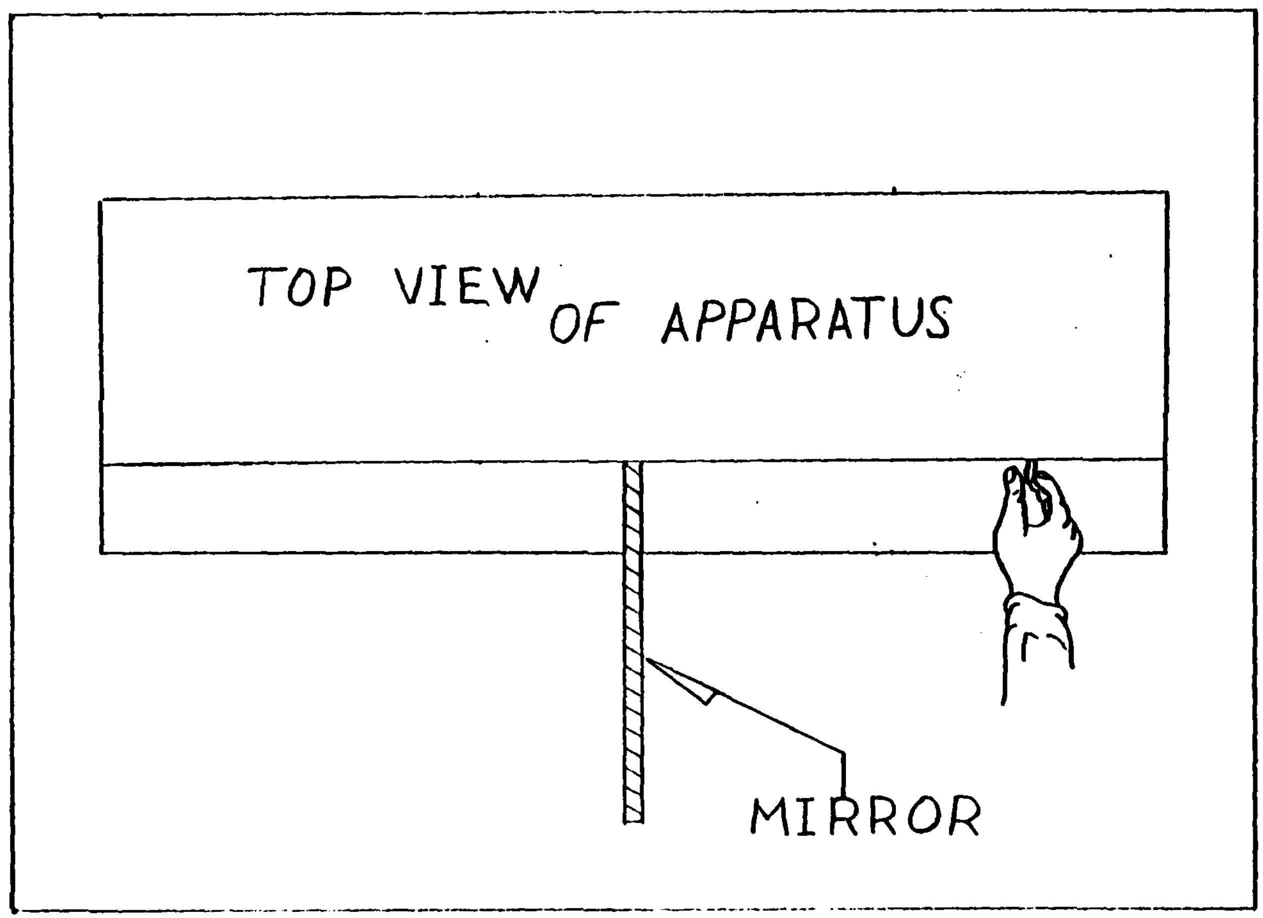

Figure 2 Illustration for explanation of symmetry.

symmetrical action, as imaged in the mirror or performed by the left hand, would also be to push the switch down. However, if the action of the right hand were to push the left-right toggle switch toward the center of the panel (a medial or left action in this case) then the mirrored action would be to push the toggle on the left side of the panel to the right (or medial) position. In this second case the switches would be activated in the opposite directions to get symmetry.

J. V. Bradley (1959) also states that the "clockwise-for-anything" tendency was found in a knob turning exercise when the right hand was used. He also found the tendency to turn the knob clockwise with the left hand was not statistically significant. In this report this would show that the symmetrical tendency weakened the left-handed responses.

This tendency to use only right-handed subjects and have them use only the preferred hand in population stereotype studies of knobs and switches has persisted to the present. H. Petropoulos and J. Brebner (1981) state, "Many researchers in the area have emphasized the need to control for handedness when studying display/control relationships (Loveless, 1962; Chapanis and Groper, 1968). Accordingly, the 100 volunteer subjects in the present study were all right handed."

The problem of using the non-preferred hand in turning knobs and throwing switches was observed by the author in his capacity as a navigator, radar navigator, and instructor navigator in the United States Air Force. From these observations, it became obvious that many more reversal errors were made by the non-preferred hand but no

data was taken at that time. Although this problem has not, to the author's knowledge, been studied directly, it caused some very serious problems in the aircraft. One of the most serious was on practice bomb runs, where a switch had to be thrown to simulate a bomb drop. This switch, by placement, had to be thrown by the left hand and was quite often pushed up (the wrong way) even though it had been placed according to regulations, which normally take into account population stereotype information. The delay through confusion was seldom more than four or five seconds but, at 500 to 600 feet per second aircraft speed, this was 2000 to 3000 feet off the target or about half a mile.

Another problem in the aircraft concerned a set of counters with corresponding knobs which had to be turned to set the aircraft position on the counters. These knobs had to be turned by the navigator's left (normally non-preferred hand) hand, often while he was looking at some other display during the initial movement of the counters. Too often the navigator would look up to see that he had increased or decreased the counter reading when he meant to do the opposite, thus losing up to 30 seconds which were needed for more critical activities. The radar navigator, sitting on the other side of the counters, seldom made such mistakes when using the right (normally preferred) hand.

Loveless and others, cited above, noted that the symmetrical arrangement of the right and left hands and arms may play a role in the movement of switches. However, none of the sources studied said anything about studying the effect of symmetry and the non-preferred hand.

Studies by Murrell (1965) and Vince (reported by Brown and Jenkins, 1947) found that some stereotypes for control movement were weakened under stress or time limited conditions. Smith (1981), on the other hand states that expectations based on customary usage are often strong and are hard to break. Here one study reported that the stereotype, if strong, should be hard to break and stress or time limitation should not affect it, while two other studies say that the stereotype might be affected by stress or time limiting.

Although the author is most familiar with reversal error in aircraft, they are not the only places where the operator of machinery must use the non-preferred hand or both hands to operate knobs and switches. Switches operated by a non-preferred hand are also found in cars, boats, industrial machinery, and computer centers to name just a few.

Thesis Objectives

The objectives of this thesis are to test the following hypotheses:

1. Using the preferred hand, there is a movement stereotype of at least 85 percent for turning on and off a selection of seven switches (see Figure 1, p. 3). Stereotyped directions are described in military design standards discussed subsequently.
2. Using the non-preferred hand will result in unacceptable reversal errors effectively weakening the stereotypes in objective 1.

3. When both preferred and non-preferred hands are used to simultaneously turn on or turn off the same type of switch, the stereotype for one or both hands will be reduced.

4. Many subjects will turn pairs of switches in the opposite direction for the same task, e.g., the left-hand control left and the right-hand control, right.

METHOD

Subjects

The subjects for this study were 120 Air Force ROTC students at Texas A&M University. These students ranged in age from 18 to 24 years and were chosen at random over a two week period. Of these subjects 30 were left handed and the remaining 90 were right handed. Of the 120 subjects, only 3 were female.

Experimental Design

To investigate the effects of the non-preferred hand on stereotypes, the on and off positioning regulations from the U. S. MIL-HDBK-759, (March 12, 1975), and employed by Kratz (1981), were used as criteria for the experiment. Table 1 presents the recommended movement directions for on and off.

TABLE 1

Conventional Control Movement Stereotypes

Function	Direction of Movement
On	Up, right, forward, clockwise, pull (push-pull-type switch)
Off	Down, left, rearward, counter-clockwise, push

To confirm these movement stereotypes against actual data the apparatus in Figures 1 and 3 (p. 3 and p. 10) was constructed and the 120 subjects, including 30 left-handed subjects, were tested in 6 groups of 20 each. These subjects were tested in accordance with the groupings in TABLE 2 (p. 11).

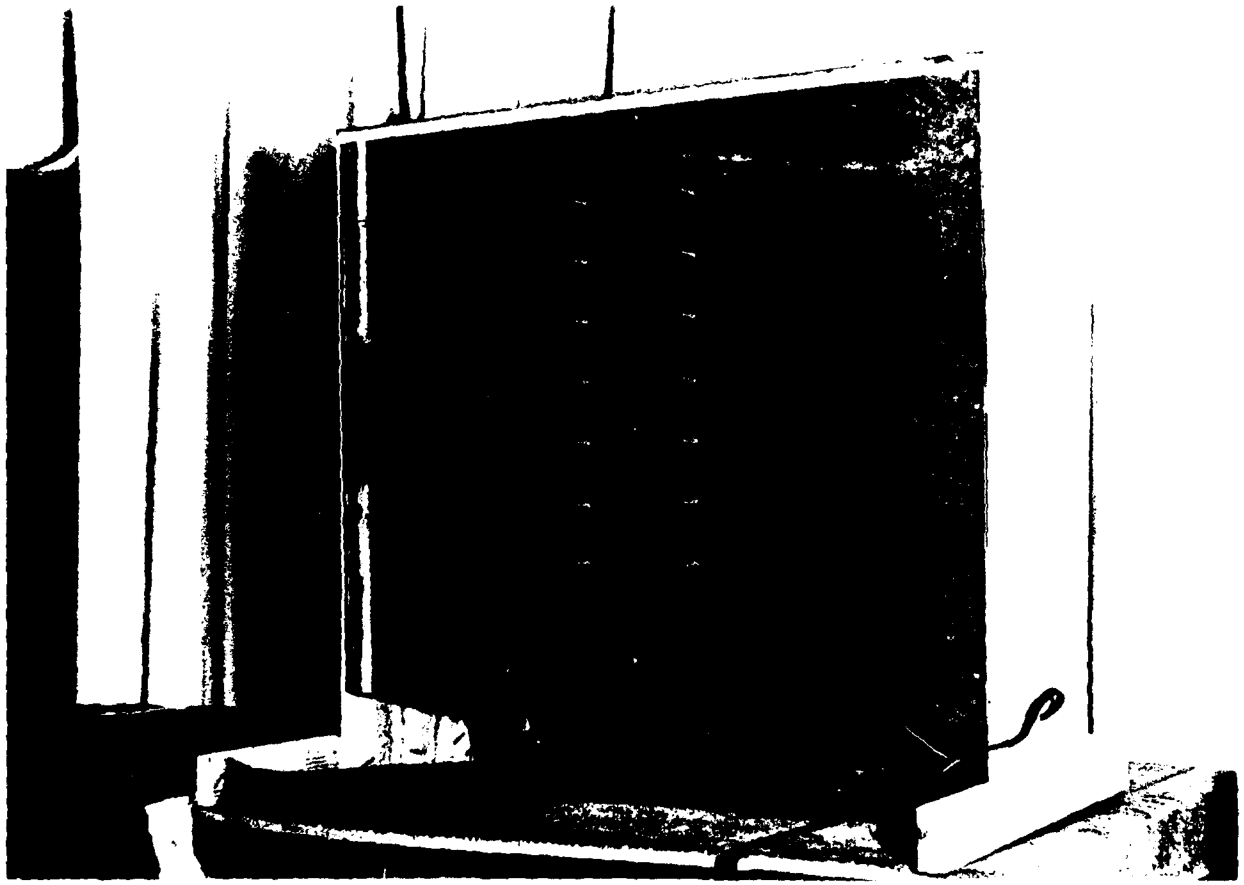

Figure 3 Back panel of test apparatus showing light control switches. Switches were activated by the test administrator.

TABLE 2

Test Groupings

ON	20 Preferred Hand--Turn Switch On 20 Non-Preferred Hand--Turn Switch On 20 Both Hands Simultaneously--Turn Switches On
OFF	20 Preferred Hand--Turn Switch Off 20 Non-Preferred Hand--Turn Switch Off 20 Both Hands Simultaneously--Turn Switches Off

For the preferred hand groups, data was taken when the right handed subjects used the right hand to turn on or off the switches on the right side of the panel only and when the left handed people used only the left hand to turn on or off the switches on the left side of the panel. To study the non-preferred hand response, the data was taken when the right-handed people used the left hand on the switches on the left side of the panel and left-handed subjects used the right hand on the switches on the right side of the panel. Also, careful track was kept of the positioning of the switches when both hands were used and the preferred and non-preferred hand data were recorded using the same criteria as above for the single hand test groups.

In each of the six categories of Table 2, there were 15 right handed and 5 left handed subjects. This was done to permit investigation also of the problem of handedness in the study.

Each subject performed seven tasks which were to turn off (or on, depending on the group) the seven switches on the instructed side of the panel corresponding to the hand used, or in the case of the dual hand tasks, the pairs of switches, as the lights by the switches were

turned on from the back. The procedure for this will be fully explained in the procedure section in this thesis.

To eliminate the factors of sequence errors and errors caused by subject order and time/environment factors, the order of the 120 subject runs was randomized by taking each run and assigning it a number from 1 to 6 from a random number table (Appendix A). These numbers correspond to the six instructions in Appendix B.

To eliminate the errors which might have been caused by the order in which each subject was asked to throw the seven switches or sets of switches, each run was randomized by using the random number table to select the order in which the switches would be thrown. This is also shown in Appendix A. The switches were numbered 1 to 7 from the top of the panel to the bottom of the panel.

Apparatus

The subjects were tested in the ROTC building, office 212 with ambient illumination held at approximately 1 Fl. The low illumination was used to make the panel lights of the apparatus readily visible, while maintaining enough light to allow the subjects to easily see the switches on the panel.

The apparatus used in this experiment was a wooden mockup with seven pairs of switches on the front panel, each switch having a corresponding red light next to it on the front panel, and seven pairs of switches on the back panel (see Figures 1 p. 3 and 3 p. 10). The switches on the back panel were used by the investigator to turn the

lights on the front panel on and off singularly or in pairs as will be explained later.

The switches on the front panel were only dummy switches which did not actually control anything. These front panel switches were all three-position switches which were placed in the center position before each run so the subject could activate the switches in the direction deemed correct by the subject for the directed function.

There were seven types of switches tested. These switches will be discussed from top to bottom as they appear in Figure 4 (p. 14). The switches were numbered from 1 at top to 7 at the bottom of the panel.

Switch number 1 was a toggle switch which can be actuated either up or down in a manner similar to the common household light switch. Switch number 2 was a toggle switch identical to switch number 1 except that it was mounted on the right side to be actuated either to the left or the right. Switch number 3 was a vertical slide switch mounted for up or down movement similar to switches found commonly on stereo and other home electronic equipment. Switch number 4 was identical to switch number 3 but mounted to be actuated left or right. The number 5 switch was a push-pull switch similar to those found in the automobile to turn the headlights on and off. The sixth switch was a rotary switch commonly found on all types of equipment. The rotary switch had a small pointer which pointed vertically and moved clockwise or counterclockwise.

The first six switches were all mounted on the vertical front panel and set to the center position so that they could be actuated in

Figure 4 Administrator in position.

either direction away from the center. The seventh switch was mounted in the horizontal plane, however. Switch number 7 was a three position toggle switch identical to switches 1 and 2 but mounteu vertically on a horizontal plane in such a manner that it could be actuated rearward (toward the subject) or forward (away from the subject).

Procedure

Each subject entered the experimental chamber and the door was closed to preclude other waiting subjects from observing the run. The subject was then seated in front of the panel and positioned himself/herself so that all the switches were within easy reach.

Each subject received appropriate taped instructions (Appendix B) as dictated by the predetermined order of testing. It was also found in a pilot study with three Air Force ROTC personnel that further instructions were necessary (these will be discussed later). After the instructions were heard, the subject was asked to place his/her hands below the appropriate vertical rows of switches and told that he/she would receive the lights in a random order on the panel. The lights were then turned on individually or in pairs according to the schedule in Appendix A. Figure 5 (p. 17) shows the administrator actuating switches.

To avoid transfer of learning, the subjects were given the switches in a random order as discussed earlier and adjacent lights remained on after they had been turned either, off or on so that there were 7 or 14 lights on when the run was over. One and two handed operation of these switches is illustrated in figures 6 and 7 (p. 18

and 19) respectively. A light did not extinguish when a given switch was turned off or on. The subject was told the switches only affected unseen machinery and not the lights. This was implemented so that a given directional response would not be reinforced, possibly resulting in learning.

The switches on the front panel were all of the three-position type which allowed them to be prepositioned in the center position giving the subject free movement in the direction chosen.

With the switches on the back of the apparatus, the experimenter then turned on the lights singularly or in pairs of like switches with one hand while sitting next to the apparatus where he could observe the subject. The subject was then to either turn on or turn off the switches on the front panel when the corresponding lights came on. The subject's actions were as directed in a taped instruction which will be discussed later.

After the subject had thrown the appropriate switches, the reactions were taken down and the switches and lights reset before the next subject was admitted. Each subject was instructed not to talk about the experiment so as not to bias other subjects.

Instructions

As stated previously, there were six taped instructions. One tape for each of the six conditions on Table 2 (p. 11) was used. The text of these six instructions can be found in Appendix B.

It was found that some further instructions were necessary for clarification. These instructions were delivered by the experimenter. These instructions were as follows:

Figure 5 Administrator actuating pair of light switches on back panel.

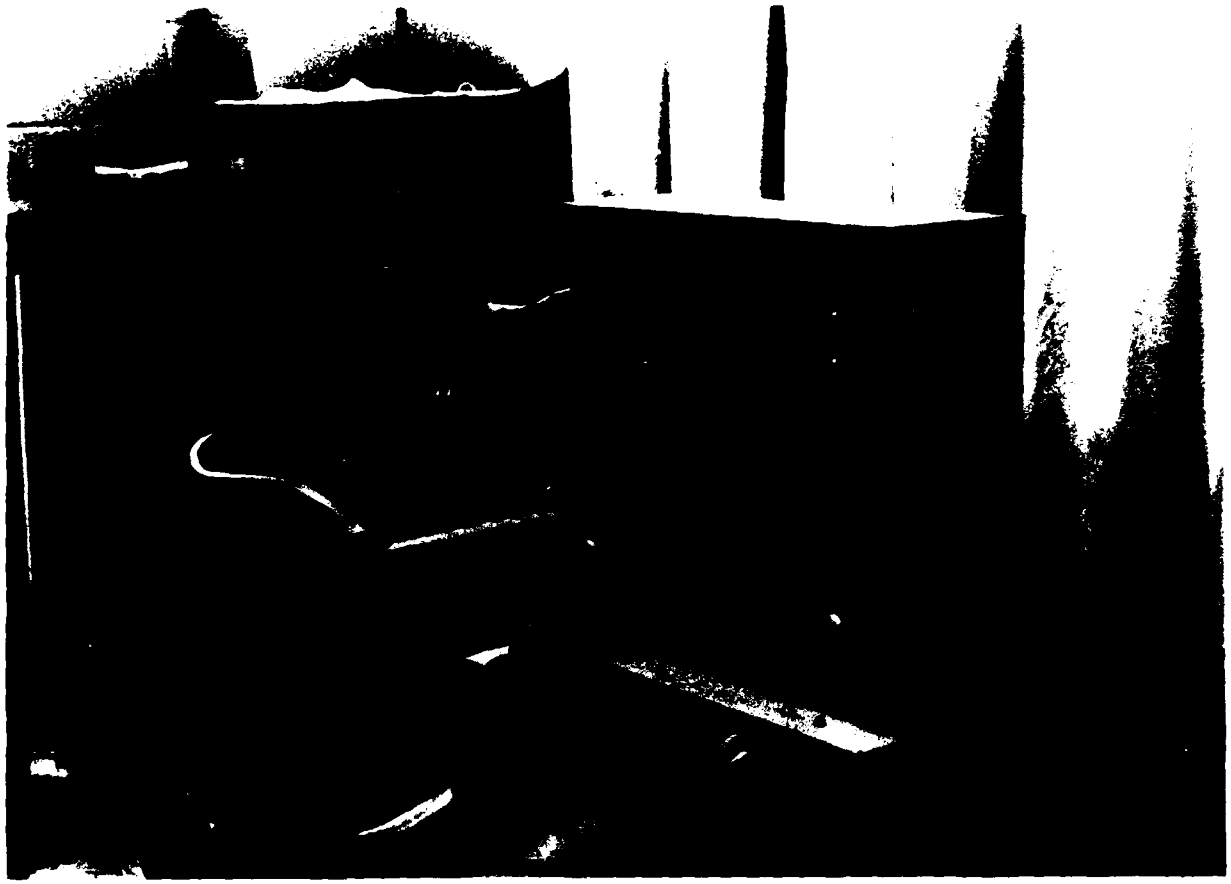

Figure 6 One handed operation by subject.

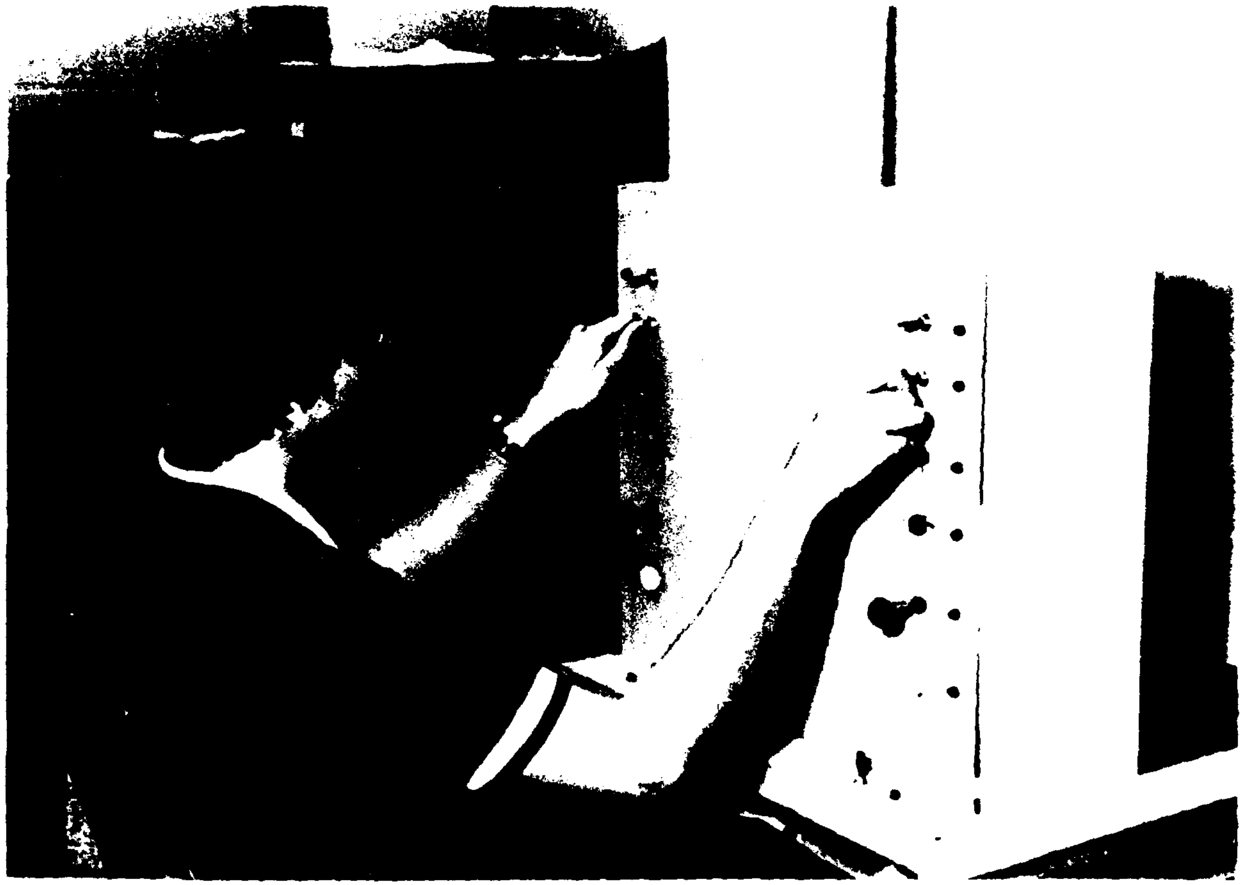

Figure 7 Two handed operation by subject.

1. You will be given the lights in rapid succession.
2. Once you have positioned a switch do not reposition it. I want your first reaction.
3. You will be given each of the seven switches only once
4. When you throw a switch you will not affect the lights. When we finish, all seven/fourteen lights will be illuminated.
5. The fifth switch down is a push-pull switch and the sixth switch down is a rotary which only turns about an eighth of a turn.

If the subject was to operate pairs of switches, one other instruction was given:

A pair of switches is the two like switches such as the top two or the bottom two, but not a diagonal combination of any kind.

The most asked question was, "Which way is off/on?" To this the experimenter's answer was, "Your instructions are to turn the switches off/on as you would normally do this."

Data Analysis

In this design, there were six groups of 20 subjects each. As already noted, each group operated with different instructions, i.e., using the left hand, right hand, or both hands, and turning switches on or turning them off under each hand condition. In addition, each subject operated seven switches or pairs of switches. Hence, four of the six groups had 140 data points each and the two two-hand operation

groups had 280 data points each, giving a total of 1120 data points for all six groups.

The maximum number responding in a given direction was 20 for any given switch condition. The frequency data was then convered to percentages and also statistically analyzed by binomial single proportion or proportions with a specified characteristic in two independent samples as described by Fleiss (1981).

In all cases, a 95% confidence two-tail test was used to test if individual groups differed from a standard 85%. This value has been recommended for design purposes (Kratz 1981). The formula for Z of the proportion is:

$$Z = \frac{|p - Po| - 1/(2n)}{\sqrt{\frac{PoQo}{n}}}$$

where Qo = 1-Po and Po = .85. Also, p = the proportion of the attribute to be tested and n = 20 or the number in the group tested. The (1/2n) is a correction for continuity, bringing normal curve probabilities into closer agreement with binomial probabilities. This factor was applied when $(1/2n) < |p - Po|$.

When testing between preferred and non-preferred hands and between one and two hand tests the following formula was used:

$$Z = \frac{|P_2 - P_1| - 1/2(1/n_1 + 1/n_2)}{\sqrt{\bar{P}\,\bar{q}\,(1/n_1 + 1/n_2)}}$$

where $\overline{q} = 1-\overline{P}$. This test was run against a 95% confidence level two-tailed test.

The Z to be tested against was therefore 1.96 in all cases and a larger Z value indicated that the single proportions differed from the 85% or that the two proportion tests differed from each other using a .05 confidence level.

RESULTS AND DISCUSSION

Stereotypes When Single Hand Used--Off Direction

According to Table 1 (p. 9), the stereotyped movements to turn off a switch are down, left, rearward, counter-clockwise, and push (push-pull controls only). Note in Table 3, all except one of the switches did show a strong tendency (75% or greater) toward established stereotypes for turn-off. However, the right-left toggle switch showed only 55% which is not statistically equivalent to the 85% stereotype level.

TABLE 3

Preferred Hand Used Alone to Turn Off

Switch	%	Z	Direction Tested	Same as 85%
U-D Toggle	80	0.313	Down	Yes
R-L Toggle	55	3.444	Left	No
U-D Slide	90	0.313	Down	Yes
R-L Slide	80	0.313	Left	Yes
I-O Switch	80	0.313	In or Push	Yes
CW-CCW Rotary	75	0.939	CCW	Yes
R-F Toggle	95	0.939	Rearward	Yes

It is strange that the response on the right-left slide switch was quite strong, 80%, while the right-left toggle was only 55%. A conjecture on this might be that the slide switch is more common in everyday life than the toggle in the left-right configuration. The slide is found in stereo equipment, the windshield wiper switches in some automobiles, and many other examples. The toggle switch,

however, is not found as commonly in this configuration. Over all, the off-direction with the preferred hand showed the expected movement stereotypes.

With non-preferred hand movements were examined (see Table 4), both the left-right switches and the rotary switch no longer were statistically 85%. Also, the raw-percentages, except the up-down

TABLE 4

Non-Preferred Hand Used Alone to Turn Off

Switch	%	Z	Direction Tested	Same as 85%
U-D Toggle	80	0.313	Down	Yes
R-L Toggle	55	3.444	Left	No
U-D Slide	80	0.313	Down	Yes
R-L Slide	45	4.698	Left	No
I-O Switch	75	0.939	In or Push	Yes
CW-CCW Rotary	65	2.192	CCW	No
R-F Toggle	95	0.939	Rearward	Yes

toggle and the rearward-forward switch, were lower than with the preferred hand.

The percent difference between the preferred and non-preferred hands were not significant as shown in Table 5. The only switch which came close to showing a significant difference was the right-left slide switch which fell exactly on the 1.96 cutoff point. In all instances, however, the percentage for the non-preferred hand is the same or less than that for the preferred hand.

TABLE 5

Preferred vs. Non-Preferred Hand Used Alone to Turn Off

Switch	%	Z	P	Direction Tested	Same
U-D Toggle	80-80	-0.395	0.800	Down	Yes
R-L Toggle	55-55	-0.317	0.550	Left	Yes
U-D Slide	90-80	0.443	0.850	Down	Yes
R-L Slide	80-45	1.960	0.625	Left	Yes
I-O Switch	80-75	0.0000	0.775	In or Push	Yes
CW-CCW Rotary	75-65	0.345	0.700	CCW	Yes
R-F Toggle	95-95	-0.725	0.950	Rearward	Yes

Stereotypes When Single Hand Used--On Direction

According to Table 1 (p. 9), the stereotyped movements to turn on a switch are up, right, forward, clockwise, and pull. Table 6 indicates that only the toggles and rotary switches showed a first response in the stereotyped direction and none of the percentages met the 85% criterion. It should be noted again that a different set of 20 subjests performed in the ON than in the OFF conditions, hence turning in the opposite direction would not be a logical inference.

When the non-preferred hand was tested for turning on a switch, it was found that there were no stereotypes in the expected direction (See Table 7). A reverse stereotype was found in one set of data. This was the actuation of the rearward-forward switch 85% of the time in the rearward direction. This is a direct contradiction to the stereotype in Table 1 (p. 9). Since the toggle was pulled rearward 95% of the time for off and 85% of the time for on, it would seem that

toggles actuated in the horizontal plane might be pulled rearward for any situation and would cause trouble in an emergency. The problem here may be in confusion between a throttle action and the push-pull switch, where rearward movement is off and on respectively.

TABLE 6

Preferred Hand Used Alone to Turn On

Switch	%	Z	Direction Tested	Same as 85%
U-D Toggle	60	2.818	Up	No
R-L Toggle	65	2.192	Right	No
U-D Slide	40	5.323	Up	No
R-L Slide	45	4.697	Right	No
I-O Switch	35	5.949	Out or Pull	No
CW-CCW Rotary	65	2.192	CW	No
R-F Toggle	35	5.949	Forward	No

TABLE 7

Non-Preferred Hand Used Alone to Turn On

Switch	%	Z	Direction Tested	Same as 85%
U-D Toggle	55	3.444	Up	No
R-L Toggle	60	2.818	Right	No
U-D Slide	50	4.070	Up	No
R-L Slide	50	4.070	Right	No
I-O Switch	60	2.818	Out or Pull	No
CW-CCW Rotary	45	4.697	CW	No
R-F Toggle	15	8.454	Forward	No

When the preferred and non-preferred hand were compared in Table 8, only the push-pull switch showed a significant difference. This was not surprising when neither hand showed a stereotype.

TABLE 8

Preferred vs. Non-Preferred Hand Used Alone to Turn On

Switch	%	Z	$\overline{P}$	Direction Tested	Same
U-D Toggle	60-55	0.000	0.575	Up	Yes
R-L Toggle	65-60	0.000	0.625	Right	Yes
U-D Slide	40-50	0.674	0.450	Up	Yes
R-L Slide	45-50	0.224	0.475	Right	Yes
I-O Switch	35-60	2.015	0.475	Out or Pull	No
CW-CCW Rotary	65-45	0.953	0.550	CW	Yes
R-F Toggle	35-15	1.807	0.250	Forward	Yes

Stereotypes When Preferred and Non-Preferred Hands Used Simultaneously--Off Direction

Under this condition, both hands were used to simultaneously turn off a pair of like switches at a time until each of the seven pairs of switches had been turned off. The data was then taken down in such a way as to reflect the responses for each run and for preferred and non-preferred hands in each run.

When only the preferred hand was looked at in Table 9, only three of the 7 switches showed a stereotype compared to 6 of 7 when only one hand was used. This indicates that the use of both hands severely

weakened all but the up-down toggle, the up-down slide and the rearward-forward toggle stereotypes for the preferred hand.

TABLE 9

Preferred Hand When Both Hands Used to Turn Off

Switch	%	Z	Direction Tested	Same as 85%
U-D Toggle	70	1.566	Down	Yes
R-L Toggle	40	5.323	Left	No
U-D Slide	85	0.000	Down	Yes
R-L Slide	45	4.697	Left	No
I-O Switch	50	4.070	In or Push	No
CW-CCW Rotary	55	3.444	CCW	No
R-F Toggle	95	0.939	Rearward	Yes

Looking at Table 10, the non-preferred hand for two-handed tasks, it was found that the left-right toggle and the left-right slide switches showed a left-for-off stereotype. Neither of these showed the stereotype in Table 9 when only the non-preferred hand was used. The push-pull or in-out switch did not show a stereotype in the two handed operation but did in the one hand test (Tables 3, p. 23 & 4, p. 24). This again indicates that there is an effect on the use of the non-preferred hand but this effect is not as clear cut over the entire set of seven switches as was the effect on the preferred hand.

TABLE 10

Non-Preferred Hand When Both Hands Used to Turn Off

Switch	%	Z	Direction Tested	Same as 85%
U-D Toggle	70	1.566	Down	Yes
R-L Toggle	70	1.566	Left	Yes
U-D Slide	85	0.000	Down	Yes
R-L Slide	70	1.566	Left	Yes
I-O Switch	45	4.697	In or Push	No
CW-CCW Rotary	60	2.818	CCW	No
R-F Toggle	95	0.939	Rearward	Yes

Again, when the preferred and non-preferred hands were compared, there was no significant difference between the hands (see Table 11). Not only was there no difference between the hands, but the Z values were extremely low in all but two cases. The most significant or largest Z values were for the right-left switches. This is understandable since they have been found to have been lacking or weak in stereotype by Bonyuet (1981).

Since Bonyuet (1981) was working with switches and mechanisms in different planes, her work may have shown a confusion of function and required action of the switch or a lack of stereotype for this type of switch. The data presented here helps to confirm the weakness of these left-right stereotypes. There may be one other explanation for the discrepancy between preferred and non-preferred hands, however. This explanation may be in symmetry as described in the Introduction.

TABLE 11

Preferred vs. Non-Preferred Hand When Both Hands Used to Turn Off

Switch	%	Z	P	Direction Tested	Same
U-D Toggle	70-70	-0.345	0.700	Down	Yes
R-L Toggle	40-70	2.472	0.550	Left	No
U-D Slide	85-85	-0.442	0.850	Down	Yes
R-L Slide	45-70	2.035	0.575	Left	No
I-O Switch	50-45	0.000	0.475	In or Push	Yes
CW-CCW Rotary	55-60	0.000	0.575	CCW	Yes
R-F Toggle	95-95	-0.725	0.950	Rearward	Yes

To examine this aspect the symmetry of all the switches were checked and the results are shown in Table 12.

To reiterate, symmetry here is the mirror action of the hands when actuating the switches. When the two-handed action was tested in this way, all the switches either showed a strong stereotype for symmetry or close to a 50-50 split between symmetric and non-symmetric operations. In the cases where symmetry called for the same switch action by both hands such as both up or down, a strong stereotype for symmetry would be an advantage. This was, in fact, what was found not only for the up-down switches, but also the in-out switches, and the forward-rearward switches. For these switching actions then, symmetry would not affect the stereotypes and would cause no problem in design.

For the switches which permit opposing actions for symmetry such as the right-left switches and the rotary switches, only 45 to 70% showed such a response. The other subjects continued to move both

controls in the same direction. For the opposing switches, a symmetric operation means that one of the switches will be actuated in the wrong direction if the switches are placed according to the stereotype in Table 1 (p. 9). For these switches, Table 12 shows that all three opposing types had a strong stereotype or at least a 50-50 rate for symmetrical operation. This would cause both a problem in operation and a weakening in the stereotypes when both hands were used simultaneously.

TABLE 12

Both Hands Used Symmetrically to Turn Off

Switch	%	Direction	Z	Same as 85%
U-D Toggle	100	Same	1.566	Yes
R-L Toggle	70	Opposing	1.566	Yes
U-D Slide	100	Same	1.566	Yes
R-L Slide	65	Opposing	2.192	No
I-O Switch	95	Same	0.939	Yes
CW-CCW Rotary	45	Opposing	4.697	No
R-F Toggle	100	Same	1.566	Yes

Stereotypes When Preferred and Non-Preferred Hands Used Simultaneously--On Direction

When both hands were used to turn on pairs of switches simultaneously, only the expected stereotype for rotary switches was found for the preferred hand (see Table 13). This time, however, the up-down toggle showed a stereotype in the wrong direction. Only 30% pushed it

up; 70% pushed it down. The up-down slide switch did not show any stereotype. The rear-forward (R-F) toggle switch again showed a reasonably strong stereotype but in the wrong direction, i.e., 80% pulled back to turn on the system. The reversal of the up-down toggle switch is very interesting because nearly all house lighting switches are arranged with up as on. Also, it would be expected that a with a strong stereotype for turning this type switch off there would be a strong stereotype in the opposite direction for turning it on. In this study however, there was actually a strong stereotype to actuate this switch downward for both on and off functions.

TABLE 13

Preferred Hand When Both Hands Used to Turn On

Switch	%	Z	Direction Tested	Same as 85%
U-D Toggle	30	6.515	Up	No
R-L Toggle	60	2.818	Right	No
U-D Slide	50	4.070	Up	No
R-L Slide	60	2.818	Right	No
I-O Switch	50	4.070	Out or Pull	No
CW-CCW Rotary	70	1.566	CW	Yes
R-F Toggle	20	7.828	Forward	No

When the non-preferred hand was examined (see Table 14), only the up-down toggle and the Rearward-Forward toggle showed a stereotype, but again it was in the wrong direction. To turn on the system, 70% and 80% pushed downward and backwrd respectively (Table 13). Both of these showeu the identical reaction as the preferred hand.

As in all the previous cases, when the preferred and non-preferred hands were compared, there was no significant difference between the two hands (see Table 15). In this case however, only two switches showed any difference at all and four of the seven were very close to a 50-50 split with the opposite reaction.

TABLE 14

Non-Preferred Hand When Both Hands Used to Turn On

Switch	%	Z	Direction Tested	Same as 85%
U-D Toggle	30	6.575	Up	No
R-L Toggle	60	2.818	Right	No
U-D Slide	50	4.070	Up	No
R-L Slide	55	3.444	Right	No
I-O Switch	50	4.070	Out or Pull	No
CW-CCW Rotary	65	2.192	CW	No
R-F Toggle	20	7.828	Forward	No

Again, to test the aspect of symmetry in the turn on condition where both hands were used Table 16 was constructed. This table shows that all the switches which require the same actuation for symmetry were 100% for symmetry. The right-left actuated switches also showed above 50% symmetry which has been discussed as causing severe problems for simultaneous actuation. The only surprise here was the rotary switch which actually shows a strong tendency (75%) for non-symmetry. The rotary switches, then, would not cause problems in simultaneous actuation with both hands.

TABLE 15

Preferred vs. Non-Preferred Hand When Both Hands Used to Turn On

Switch	%	Z	$\overline{P}$	Direction Tested	Same
U-D Toggle	30-30	-0.224	0.300	Up	Yes
R-L Toggle	60-60	-0.323	0.600	Right	Yes
U-D Slide	50-50	-0.316	0.500	Up	Yes
R-L Slide	60-65	0.000	0.575	Right	Yes
I-O Switch	50-50	-0.316	0.500	Out or Pull	Yes
CW-CCW Rotary	70-65	0.000	0.675	CW	Yes
R-F Toggle	20-20	-0.280	0.200	Forward	Yes

TABLE 16

Both Hands Used Symmetrically to Turn On

Switch	%	Direction	Z	Same as 85%
U-D Toggle	100	Same	1.566	Yes
R-L Toggle	50	Opposing	2.818	No
U-D Slide	100	Same	1.566	Yes
R-L Slide	65	Opposing	2.192	No
I-O Switch	100	Same	1.566	Yes
CW-CCW Rotary	25	Opposing	7.202	No
R-F Toggle	100	Same	1.566	Yes

Single Handed Actuation vs. Two Handed Actuation

When the single hand actuations were tested against the dual-handed actuation, there was no statistical difference but it was noted in almost every case that the raw percentage was lower in the dual handed tasks (see Tables 17 through 20). For the switches actuated in the same direction for symmetry, this difference can only be explained by the interaction of the two hands. For the switches which have opposite actions for symmetric operation, the interaction of the hands is confounded with the symmetry of the hands to cause the differences.

TABLE 17

Preferred Single Hand vs. Preferred Hand When Both Hands Used to Turn Off

Switch	%	Z	P	Direction Tested	Same
U-D Toggle	80-70	0.365	0.750	Down	Yes
R-L Toggle	55-40	0.633	0.475	Left	Yes
U-D Slide	90-85	0.000	0.875	Down	Yes
R-L Slide	80-45	1.960	0.625	Left	Yes
I-O Switch	80-50	1.657	0.650	In or Push	Yes
CW-CCW Rotary	75-55	0.994	0.650	CCW	Yes
R-F Toggle	95-95	-0.725	0.950	Rearward	Yes

For the turn-off (Tables 18 and 19), it can be seen that the right-left switches, and the rotary switch show 15 percentage points or more difference between single-hand operation and dual-hand operation while

the up-down and rearward-forward switches showed only 10 percentage points or less. This indicates that the two effects of symmetry and two hands used together may be additive but it cannot be positively stated from this study.

The on actuations do not show the above consistency. This set of data, however, has not shown very strong trends or any stereotypes so the inconsistencies are not surprising.

TABLE 18

Non-Preferred Single Hand vs. Non-Preferred When Both Hands Used to Turn Off

Switch	%	Z	$\overline{P}$	Direction Tested	Same
U-D Toggle	80-70	0.365	0.750	Down	Yes
R-L Toggle	55-70	0.653	0.625	Left	Yes
U-D Slide	80-85	0.000	0.825	Down	Yes
R-L Slide	45-70	2.035	0.575	Left	No
I-O Switch	75-45	1.614	0.600	In or Push	Yes
CW-CCW Rotary	75-60	0.000	0.625	CCW	Yes
R-F Toggle	95-95	-0.725	0.950	Rearward	Yes

TABLE 19

Preferred Single Hand vs. Preferred Both Hands When Used to Turn On

Switch	%	Z	$\overline{P}$	Direction Tested	Same
U-D Toggle	60-30	1.589	0.450	Up	Yes
R-L Toggle	65-60	0.000	0.625	Right	Yes
U-D Slide	40-50	0.674	0.450	Up	Yes
R-L Slide	45-60	1.119	0.525	Right	Yes
I-O Switch	35-50	1.131	0.425	Out or Pull	Yes
CW-CCW Rotary	65-70	0.000	0.675	CW	Yes
R-F Toggle	35-20	1.252	0.275	Forward	Yes

TABLE 20

Non-Preferred Single Hand vs. Non-Preferred Both Hands When Used to Turn On

Switch	%	Z	$\overline{P}$	Direction Tested	Same
U-D Toggle	55-30	1.279	0.425	Up	Yes
R-L Toggle	60-60	-0.323	0.600	Right	Yes
U-D Slide	50-50	-0.316	0.500	Up	Yes
R-L Slide	50-55	0.000	0.525	Right	Yes
I-O Switch	60-50	0.318	0.550	Out or Pull	Yes
CW-CCW Rotary	45-65	1.573	0.550	CW	Yes
R-F Toggle	15-20	0.294	0.175	Forward	Yes

Note: Tables 23 and 24 in Appendix C present a summary of the percentage data from all studies.

CONCLUSIONS

The first hypothesis examined in this study was that certain movements for turning switches on or off are stereotypic. These stereotypes were given in Table 1, page 9. To test these stereotypes, only the preferred hand was examined, a procedure adopted in the numerous studies cited in the introduction. The data indicated that the off switching movements showed strong stereotypes for down, in or push (for the push-pull switch), counter clockwise, and rearward. The left movement, however, was not as strong a stereotype. There were, in fact, two types of switches which were left-right actuated, a slide switch and a toggle. Since the slide switch did show a strong stereotype but the toggle switch did not show a stereotype, two explanations are proposed. The first is that the type of switch makes a difference in the stereotype and the second is that this type of movement for off functions is confusing causing varying results. The second explanation is more plausible. It is concluded that the left-right activated switch should be avoided in applications where reversal errors are critical, such as an emergency off switch.

When the movements for switching on were studied for the preferred hand alone, no stereotypes were found. All seven switches in the study showed between 45% and 65% for the expected movements from Table 1. This is truly amazing in view of the strong stereotypes found for the off-movements. From the data collected, it must be concluded that there are no strong stereotypes for turning on a switch. Due to the extraordinary results of this study, however, it

would be wise to investigate the possibility of some artifact in the experiment which caused the confusion in practically all of the on movement portions of the study. This will be discussed further in the recommendations section.

The second hypothesis was that the use of the non-preferred hand would cause unacceptable reversal errors due to a weakening of the stereotypes. The conclusion here is that the use of the non-preferred hand does reduce somewhat the strength of the stereotypes since the raw percentages in 11 of the 14 cases (Tables 5, p. 25 and 8, p. 27) were lower than those for the preferred hand. The remaining conditions had percentages which were exactly the same for both cases. This difference was not statistically significant in any of the cases at a .05 confidence interval, however. From these two facts, then, it can be concluded that the use of the non-preferred hand would not significantly affect a statistical study unless the statistical tests were very powerful. It can also be concluded that switches which must be used in critical situations should be placed so that the predominantly right-handed population would use the right hand for switching because even a small percentage of errors in a critical situation could be disastrous.

The third hypothesis was that the use of both hands simultaneously to actuate two switches of the same kind would cause more errors than using only the preferred hand alone. When the switches were turned off, comparing Tables 5 (p. 25) and 11 (p. 30), there were consistent decreases in the percentages when both hands were used except for the forward-rearward switch which will be discussed later.

From this comparison it is concluded that the use of both hands together weakens the stereotypes. Two possible explanations for this weakening: are the simple interaction of hands caused confusion and the assumed symmetry led to a reversal error with one hand.

It can be concluded that an assumption of symmetry may have led to reversal errors. A look at Tables 15 (p. 34) and 16 (p. 34)will show that all the switches which have opposing symmetry showed symmetry between 45% and 70%, except the rotary switch for turn on movement which was 25%. Effectively 50% of all actuations of this type switch by both hands resulted in one reversal error. The conclusion, then, is that many subjects assumed a symmetrical direction of turn, thus weakening the stereotypes.

The same cannot be said of the switch movements for which the symmetrical action is in the same direction. For these there was a 95% to 100% symmetrical actuation which means that symmetry actually aided the stereotypes in this case. Pushing one control up and the other control down is not tenable. The conclusion is that symmetry did not cause the weakening of the stereotypes. From the symmetry conclusions it can be concluded that there is some other factor in the interaction of the hands which causes the overall weakening of the stereotypes.

Another conclusion reached in this study which was not covered by the hypotheses was that the forward-rearward toggle switch or a similar arrangement should not be used in a critical application. The reason for this conclusion is that 5 of the 6 conditions showed 85% to 95% of the subjects pulled the switches rearward whether to turn on or

turn off the switch. This would make this type switch unreliable in a critical situation, especially if the switch should have been turned on.

RECOMMENDATIONS FOR FURTHER RESEARCH

The first recommendation for further research is a study to determine the effect of switch type on the left-right movement. This would establish whether or not the type of switch truly affected the lack of stereotype found in this research. This could be done in a similar fashion to the present study. The panel would be set up with various types of left-right actuating switches. Questions could be asked afterward as to the type of system the subject thought was being activated.

Secondly, a study should be run to test the switching-on stereotypes with the preferred hand, since the data in this study was so negative, and so many other studies have shown the conventional stereotypes that the military was convinced to use them as design standards. This study could be done in a number of ways, including the methods of this study. A broader population should also be tested to see if something in the training of the ROTC students may have caused this discrepancy.

A further study of Air Force personnel who have been in the service for a period of 5 to 10 years should be carried out to see what changes may have occurred in these stereotypes through constant training and practice. This study should be conducted under the same conditions in which the present study was conducted. This should be done after a second study to verify the results of this study so that the present results can be verified on other groups of people entering the Air Force from different routes such as Officer Training School

and the Air Force Academy. These groups may show differences due to intensive training.

Also, a study should be done to find the specific causes of the weakened stereotypes when only the non-preferred hand is used. This may be accomplished, in part, by having the subject run a short series of switches (3 or 4 on each side) individually with the right and left hands. After the switches have been actuated, the subject would be asked what caused the responses. The subjects may give insights into the real reasons for the non-stereotypic movements made.

Since the stereotypes for the rearward-forward switches and most of the stereotypes for all the on switches were less than the expected 85% statistic, it is recommended that a study identical to this one be carried out except that a wider population and a larger sample for each condition be used. The wider population would not only test the accepted stereotypes over a broader range of backgrounds but would test the possibility that the normal stereotypes of the Air Force ROTC students is somehow being weakened because of the training they receive or other factors in the Corps at Texas A&M University. The larger groups would make the statistical analysis more powerful.

The lights used may have been a factor also in the lack of stereotype for the switch-on condition. The fact that lights stayed on regardless of the subject's action may have caused some confusion. For this reason, a similar study should be carried out using the same type apparatus but without the lights. The subject could be prompted to turn on the switches by a verbal command using a number system.

It is also recommended that the other stereotypes in the U. S. MIL-HDBK-759 (March 12, 1975), be tested in similar manner to check their continued validity (see Table 21).

TABLE 21

Stereotypes to be Tested in Future

Function	Direction of Movement
Right	Clockwise, right
Left	Counterclockwise, left
Raise	Up, back
Lower	Down, forward
Retract	Up, rearward, pull
Extend	Down, forward, push
Increase	Forward, up, right, clockwise
Decrease	Rearward, down, left, counterclockwise,
Open Valve	Counterclockwise
Close Valve	Clockwise

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APPENDIX A

RANDOM SELECTION FOR RUNS

RANDOM SELECTION FOR RUNS

The single number at the beginning of each row denotes the conditions to be given on tape (see Appendix B for full instructions).

The conditions were as follows:

1. Use right hand only to turn off switches.
2. Use left hand only to turn off switches.
3. Use both hands simultaneously to turn off switches.
4. Use right hand only to turn on switches.
5. Use left hand only to turn on switches.
6. Use both hands simultaneously to turn on switches.

The seven numbers to the right denote the order of the seven runs from 1 at top to 7 at bottom as seen in Figure 1 on page 3.

Using these designations, the following random order was selected from a random number table.

TABLE 22

Random Order of Runs for Six Conditions

4	3 6 2 7 5 4 1	3	7 6 2 4 5 3 1	6	6 3 1 5 4 7 2
6	4 3 1 2 5 7 6	1	1 4 5 2 7 3 6	3	3 4 7 6 1 2 5
3	3 4 2 7 6 1 5	4	3 6 7 4 2 1 5	1	5 6 3 1 7 4 2
2	7 3 1 5 4 6 2	2	7 6 4 2 1 5 3	6	1 3 4 5 6 7 2
2	7 6 2 4 1 3 5	3	4 5 7 3 1 6 2	5	4 2 1 6 7 5 3
6	6 7 4 2 3 1 5	5	2 7 1 4 3 6 5	2	5 6 1 3 4 7 2
2	1 4 5 7 3 2 6	1	3 7 5 6 4 2 1	5	3 2 7 1 6 4 5
4	1 2 4 6 5 3 7	5	5 6 1 2 4 7 3	6	6 3 2 5 7 1 4
3	4 3 6 7 1 5 2	5	5 6 1 3 4 7 2	5	6 2 5 7 4 3 1
5	2 6 5 3 1 7 4	2	1 2 6 3 4 5 7	6	3 5 2 6 1 7 4
5	6 4 7 2 3 5 1	2	6 7 1 2 4 5 3	5	4 2 7 3 6 1 5
4	6 7 3 2 4 5 1	1	1 4 3 7 2 6 5	4	6 4 3 2 1 7 5
5	1 7 2 3 4 6 5	3	4 5 1 7 6 2 3	5	7 5 1 3 2 6 4
3	2 3 1 7 5 4 6	5	5 2 1 4 6 7 3	4	6 2 4 1 3 5 7
3	1 3 2 4 7 5 6	1	2 1 3 6 5 4 7	4	3 7 2 5 6 4 1
1	1 3 6 2 7 5 4	2	2 6 4 3 7 1 5	3	5 3 4 7 2 6 1
4	2 5 6 1 7 4 3	5	1 3 7 2 6 5 4	3	4 6 7 3 1 2 5
2	4 7 5 1 2 6 3	3	3 4 1 2 7 6 5	1	2 6 7 1 3 5 4
4	5 3 2 7 1 6 4	2	6 5 3 4 1 2 7	5	6 3 7 4 5 1 2
5	5 3 7 4 1 6 2	6	6 3 4 5 2 1 7	2	4 1 3 6 2 5 7
6	7 6 4 1 5 2 3	2	4 1 3 6 2 5 7	1	5 3 7 2 6 1 4
2	4 3 2 5 6 7 1	1	5 7 1 3 4 2 6	6	5 6 7 1 4 2 3
1	7 3 4 2 1 6 5	1	6 5 7 2 3 4 1	4	7 5 4 1 6 3 2
6	5 6 4 2 1 7 3	6	5 1 6 3 4 2 7	1	5 6 2 3 1 4 7
1	3 2 6 4 1 7 5	6	4 5 1 6 3 7 2	5	7 6 1 3 5 2 4
1	5 2 6 4 3 1 7	2	3 1 5 7 6 2 4	6	3 1 7 6 2 4 5
1	3 4 5 2 7 1 6	2	7 3 4 6 5 1 2		
2	5 7 1 3 6 2 4	5	6 2 7 1 3 4 5		
4	4 1 3 6 7 2 5	5	1 6 7 4 3 2 5		
3	3 5 6 7 2 4 1	3	7 1 3 4 2 5 6		
4	4 3 5 2 7 6 1	4	4 1 5 3 2 6 7		
6	6 5 1 2 3 4 7	3	5 4 7 6 3 1 2		
4	6 3 4 2 5 7 1	1	2 1 7 5 3 4 6		
1	7 6 3 1 5 4 2	5	3 6 2 1 7 5 4		
2	3 1 5 7 6 4 2	6	1 7 3 2 6 4 5		
3	6 2 5 7 1 3 4	3	4 1 3 5 2 6 7		
4	4 2 6 1 7 5 3	6	1 3 6 5 7 4 2		
2	6 4 1 2 7 5 3	4	5 2 1 6 3 4 7		
6	3 1 6 4 2 5 7	3	7 4 3 5 1 6 2		
1	1 4 2 5 7 3 6	4	7 5 2 3 6 4 1		
3	5 2 6 3 4 1 7	3	5 4 3 2 1 7 6		
1	7 4 6 3 1 2 5	5	6 5 4 3 1 7 2		
4	4 2 1 3 7 5 6	2	2 6 7 4 1 5 3		
3	4 5 1 7 6 2 3	6	5 1 7 6 3 4 2		
1	2 4 7 1 3 6 5	6	5 2 6 1 7 4 3		
6	3 5 2 6 7 4 1	2	6 5 7 2 1 4 3		
4	4 5 1 7 6 2 3	4	3 7 1 2 4 5 6		

APPENDIX B

SIX INSTRUCTION SETS FOR RUNS

INSTRUCTIONS ON TAPE

Tapes 1 & 2 had 69 of 70 words of instruction identical

Tapes 4 & 5 had 75 of 76 words the same and 70 of the 76 words identical with 1 & 2 respectively.

The 3 and 6 tapes were much the same as the others but the plural values were substituted such as pair of switches for switch, both hands for right hand and the word simultaneous was added when the subject was told to turn on/off the switches as quickly as possible.

Tape #1.

You are sitting before a simulated control panel. The switches on this panel control unseen machinery and the lights next to the switches are warning lights for this machinery. When you see a light, it means the machinery is about to malfunction. So you must turn off the switch corresponding to that light as quickly as you can. You are to use only your right hand to turn off the switches.

Tape #2.

You are sitting before a simulated control panel. The switches on this panel control unseen machinery and the lights next to the switches are warning lights for this machinery. When you see a light, it means the machinery is about to malfunction. So you must turn off the switch corresponding to that light as quickly as you can. You are to use only your left hand to turn off the switches.

Tape #3.

You are sitting before a simulated control panel. The switches on this panel control unseen machinery and the lights next to the switches are warning lights for this machinery. When you see a pair of lights, it means the machinery is about to malfunction. So you must turn off the switches corresponding to the pair of lights, simultaneously and as quickly as you can. You are to use both hands simultaneously to turn off the switch pair.

Tape #4.

You are sitting before a simulated control panel. The switches on this panel control unseen backup machinery and the lights next to the switches are warning lights for this machinery. When you see a light, it means a machine is about to malfunction. So you must turn on the backup machine with the switch corresponding to the light as quickly as you can. You are to use only your right hand to turn on the switches.

Tape #5.

You are sitting before a simulated control panel. The switches on this panel control unseen backup machinery and the lights next to the switches are warning lights for this machinery. When you see a light, it means a machine is about to malfunction. So you must turn on the backup machine with the switch corresponding to the light as quickly as you can. You are to use only your left hand to turn on the switches.

Tape #6.

You are sitting before a simulated control panel. The switches on this panel control unseen backup machinery and the lights next to the switches are warning lights for this machinery. When you see a pair of lights, it means a machine is about to malfunction. So you must turn on the backup machine with the the pair of switches corresponding to the lights as quickly as you can. You are to use both hands simultaneously to turn on the pair of switches.

APPENDIX C

COMPOSITE RESULTS TABLE

TABLE 23
Master Table for
Single Hand Used to Turn Off and On

Switch		Off			On	
		Pref.Hand	Non-Pref.Hand		Pref.Hand	Non-Pref.Hand
U-D Toggle	D	80	80	U	60	55
R-L Toggle	L	55	55	R	65	60
U-D Slide	D	90	80	U	40	50
R-L Slide	L	80	45	R	45	50
I-O Switch	In	80	75	Out	35	60
CW-CCW Rotary	CCW	75	65	CW	65	45
R-F Toggle	Rear	95	95	For	35	15

TABLE 24
Master Table for
Both Hands Used to Turn Off and On

Switch		Off				On		
		Pref.Hand	Non-Pref Hand	Sim.		Pref.Hand	Non-Pref Hand	Sim.
U-D Toggle	D	70	70	100	U	30	30	100
R-L Toggle	L	40	70	70	R	60	60	60
U-D Slide	D	85	85	100	U	50	50	100
R-L Slide	L	45	70	65	R	60	55	65
I-O Switch	In	50	45	95	Out	50	50	100
CW-CCW Rotary	CCW	55	60	45	CW	70	65	25
R-F Toggle	R	95	95	100	F	20	20	100

APPENDIX D

TABLES OF RAW DATA

RAW DATA

TABLE 25
Raw Data for
Preferred Hand Used to Turn Off Switches

U-D Toggle	U	D	D	D	D	D	D	U	D	D	D	U	D	D	D	D	D	D	D	U
L-R Toggle	R	L	L	R	R	R	R	L	R	L	L	R	L	L	R	R	L	L	L	L
U-D Slide	D	D	D	D	D	D	D	D	D	D	D	U	D	D	D	U	D	D	D	D
L-R Slide	R	L	R	L	R	L	L	L	R	L	L	L	L	L	L	L	L	L	L	L
I-O Switch	I	O	I	I	I	I	I	I	I	I	I	I	I	I	I	O	I	I	I	O
Rotary	R	L	R	L	L	L	L	R	L	R	L	R	L	L	L	L	L	L	R	L
R-F Toggle	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	F	R	R	R
Left Handed		L							L				L						L	L

TABLE 26
Raw Data for
Non-Preferred Hand Used to Turn Off Switches

U-D Toggle	D	D	D	U	U	D	D	U	D	D	D	D	D	D	D	U	D	D	D	D
L-R Toggle	R	L	L	L	R	R	L	L	R	R	L	R	L	L	R	L	R	R	L	L
U-D Slide	U	D	D	U	U	D	D	D	D	U	D	D	D	D	D	D	D	D	D	D
L-R Slide	R	L	L	L	R	R	L	R	R	R	L	L	R	L	L	R	R	R	L	R
I-O Switch	O	O	I	O	I	I	O	I	I	I	I	I	I	I	O	I	I	I	I	I
Rotary	L	L	L	L	R	L	L	L	L	R	L	L	L	L	L	R	L	R	L	R
R-F Toggle	R	R	R	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Left Handed					L			L	L		L									L

Note: For the Rotary Switch L = CCW and R = CW

TABLE 27
Raw Data for
Preferred Hand Used to Turn On Switches

U-D Toggle	D	D	D	U	U	U	D	U	U	D	U	U	U	D	U	D	U	U	D	D
L-R Toggle	R	L	R	R	R	R	L	L	R	R	L	R	R	L	R	R	R	R	L	L
U-D Slide	D	D	D	D	U	U	U	D	U	D	D	U	U	D	U	D	D	D	D	U
L-R Slide	L	L	R	R	R	L	R	L	L	L	R	R	R	L	L	R	R	L	L	L
I-O Switch	I	I	O	I	I	I	I	O	I	O	I	I	O	O	O	I	I	I	I	O
Rotary	R	L	R	L	R	R	L	L	R	L	R	R	R	L	R	R	R	R	L	L
R-F Toggle	R	R	F	R	F	F	R	R	R	R	R	F	F	R	R	R	F	F	R	R
Left Handed		L						L					L	L						L

TABLE 28
Raw Data for
Non-Preferred Hand Used to Turn On Switches

U-D Toggle	D	D	U	D	D	U	U	D	U	U	U	U	U	D	U	D	U	U	D	D
L-R Toggle	L	R	L	R	L	R	L	L	R	R	R	L	R	R	L	R	R	R	R	R
U-D Slide	D	D	U	D	D	D	D	U	U	U	U	U	U	D	U	D	U	D	D	U
L-R Slide	L	L	L	R	R	R	L	L	R	R	R	L	R	L	L	R	R	L	R	R
I-O Switch	I	I	I	O	O	I	I	I	O	O	O	O	I	O	O	O	O	O	I	O
Rotary	R	L	L	R	L	L	R	L	R	R	R	L	L	L	R	L	R	L	R	R
R-F Toggle	R	R	F	R	R	R	R	R	R	F	F	R	R	R	R	R	R	R	R	R
Left Handed	L		L			L											L		L	

Note: For the Rotary Switch L = CCW and R = CW

TABLE 29
Raw Data for
Both Hands Used to Turn Off Switches

U-D Toggle	L	D	D	D	U	D	D	U	D	U	D	D	U	U	D	U	D	D	D	D	D
	R	D	D	D	U	D	D	U	D	U	D	D	U	U	D	U	D	D	D	D	D
L-R Toggle	L	L	R	R	L	L	L	L	L	L	L	L	L	L	L	R	L	L	L	L	R
	R	L	L	L	L	R	L	R	R	R	R	R	R	R	R	R	L	R	R	R	R
U-D Slide	L	D	D	D	D	U	D	D	D	D	D	D	D	U	D	D	D	D	D	D	U
	R	D	D	D	D	U	D	D	D	D	D	D	D	U	D	D	D	D	D	D	U
L-R Slide	L	L	R	R	L	R	L	L	L	R	L	R	L	L	L	R	L	L	L	L	R
	R	L	L	L	L	L	L	R	R	L	R	L	R	R	R	R	L	R	L	R	R
I-O Switch	L	I	O	I	I	I	I	I	I	O	I	O	I	O	O	I	O	O	O	O	O
	R	I	O	I	I	O	I	I	I	O	I	O	I	O	O	I	O	O	O	O	O
Rotary	L	L	L	R	L	R	L	L	L	R	L	L	L	L	R	R	L	L	L	R	L
	R	L	L	L	L	R	L	R	L	R	R	R	L	R	L	R	L	R	R	R	R
R-F Toggle	L	R	R	R	R	R	R	R	R	R	R	R	R	R	R	F	R	R	R	R	R
	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	F	R	R	R	R	R
Left Handed						L										L	L		L		L

Note: For the Rotary Switch L = CCW and R = CW

TABLE 30
Raw Data for
Both Hands Used to Turn On Switches

U-D Toggle	L	U	U	U	U	D	D	D	D	D	D	D	D	U	D	D	D	D	D	U	D
	R	U	U	U	U	D	D	D	D	D	D	D	D	U	D	D	D	D	D	U	D
L-R Toggle	L	R	R	R	L	L	L	R	R	R	L	L	L	L	R	R	R	L	R	R	R
	R	R	L	R	R	R	R	L	L	L	L	L	R	R	L	L	R	R	R	R	R
U-D Slide	L	U	D	U	U	D	U	U	D	D	D	U	D	U	D	U	D	D	D	U	U
	R	U	D	U	U	D	U	U	D	D	D	U	D	U	D	U	D	D	D	U	U
L-R Slide	L	R	R	R	L	L	L	L	R	R	L	L	R	L	R	R	L	L	R	R	R
	R	R	L	R	R	R	R	R	L	L	L	L	L	R	L	L	R	R	R	R	R
I-O Switch	L	0	I	0	I	I	I	0	0	0	0	0	I	I	I	0	I	0	I	I	0
	R	0	I	0	I	I	I	0	0	0	0	0	I	I	I	0	I	0	I	I	0
Rotary	L	R	L	L	L	R	R	L	R	L	L	R	L	R	L	R	R	R	R	R	R
	R	R	R	L	L	L	R	R	R	R	L	R	L	R	R	R	R	R	R	R	R
R-F Toggle	L	F	R	R	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	F	F
	R	F	R	R	F	R	R	R	R	R	R	R	R	R	R	R	R	R	R	F	F
Left Handed			L		L	L									L					L	

VITA

Richard Lee Lenz was born November 13, 1945 to Mr. and Mrs. John J. Lenz of Anderson, Indiana. He was graduated from Middletown High School in 1963 and attended General Motors Institute, graduating with a Bachelor of Mechanical Engineering in 1968.

During the period at General Motors Institute he was in a co-operative program with Delco-Remy Division of General Motors Corporation where he was employed until 1971. After working as an electrician until 1972, he entered the U. S. Air Force where he is presently employed.

He also did work for a Masters in Business Administration at Texas Christian University until the Air Force sent him to Texas A&M University to pursue a M.S. in Industrial Engineering.

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LME

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